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SPEED CONTROL FOR BLDC MOTOR USING PID AND FUZZY PID CONTROLLERS

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ABSTRACT

Brushless DC (BLDC) motors are gaining more importance in industrial applications because of their high speed, high efficiency, high torque and low volume. Here in this paper, an improved Fuzzy PID controller to control speed of Brushless DC motor was proposed. The speed controller for BLDC motor is designed using proportional–integral–derivative (PID) controller and Fuzzy proportional–integral–derivative controller. This paper provides comparisons between the performance of conventional PID controller and Fuzzy PID controller. Tuning the PID parameters for BLDC motor to get satisfied speed control characteristics is difficult. So to have the accurate speed control characteristics, to control the BLDC motor, a Fuzzy PID controller has been designed. The modeling, control and simulation of the BLDC motor has carried out using MATLAB for different speeds and loads. The simulation results provide satisfactory and better control performance of Fuzzy PID controller than the conventional PID controller for the BLDC motor.

KEYWORDS: Brushless DC (BLDC) Motors, Proportional Integral Derivative (PID) Controller, Fuzzy PID Controller

INTRODUCTION

Today in the emerging industrial applications the BLDC motor is gaining importance because of its salient features like high speed, no commutator, no brushes, less maintenance, high efficiency, controlled electronically easily, etc. The permanent magnet brushless dc motor consists of the permanent magnets on rotor which provides the necessary air gap flux instead of the armature winding. BLDC motor is conventionally defined as a permanent magnet synchronous motor with a trapezoidal Back EMF waveform shape used for sensing the rotor position to drive the motor in a phase sequence. Recently, high performance BLDC motor drives are being widely used for different important applications like variable speed drives, industrial applications and electrical vehicles.

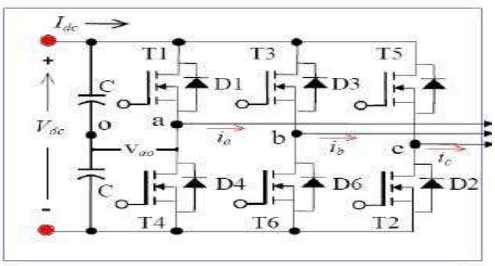
Here in this paper the BLDC motor drive modeling is very difficult in control system, simulation and parameters tuning. PID controllers are extensively used in servo control system. The PID controllers performance is sensitive to different parameter variations. Servomotors are used in automatic systems, drives for printers, tape recorders and robotic manipulators. Tuning of the PID coefficients to optimizing to the control system. One of the popular feedback controller of PID algorithm used industrial process. It is a robust and easy to understand and provides excellent control performance to the varied dynamic characteristics of process plant. The Proportional- Integral- Derivative (PID) controller is a most common and useful algorithm in control systems engineering

In recent years many of applications of Fuzzy Logic (FL) have increased significantly. Fuzzy logic is a narrow sense and a logical system in the sense traditional multi valve logical system. FL system is designed with the linguistic rules by forming IF-THEN rules those are in the form of statements. In this we can designs and implements the minimum number of rules. Fuzzy PID control is some times more difficult in non-linear and other process for standard model. Fuzzy Logic rules are based on the membership functions with values varying between 0 and 1. In this proposed system Fuzzy PID control algorithm maintaining the reference speed of the motor and controlling, it is gives simple and effective control, robustness, good dynamic response, and observing the rising time, overstrike characteristics. Here Fuzzy Logic control system observes more advantages and some of disadvantages like it is cannot be achieved by trial and error, these can effects for some of applications. So that it further simplify system to tuning the parameters and developing the rules for best results.

The aim of this proposed system to improve the dynamic response, rise time and accurate speed control for BLDC motor applying a reference speed with load and without loads and varies different speeds. This paper was designed by the using of conventional PID controller and improved Fuzzy PID controller to compares the each values between those two controllers each other using simulated MATLAB software design.

SPEED CONTROL SYSTEM OF BLDC MOTOR

The three phase BLDC Motor speed controller block diagram is shown below in Figure 1. Here BLDC Motor control done by two loops in the diagram. Rules based Fuzzy PID/PID controller inner loop. In this loop Hall effect sensors produces the electromotive forces and it gives gating signals to Inverter. Feedback outer loop directly controls the BLDC motor speed by varying the input voltage.



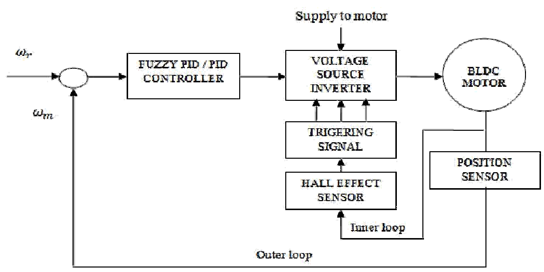


Figure 1: Block Diagram of Speed Control of BLDC Motor **Figure 2: Voltage Source Inverter**

In above Figure 2 the three phase power converter consists of six power MOSFETs to run the BLDC Motor. The switches in the voltage source inverter are adjusted to produce the required average phase voltage and average phase current so as to supply the required power to the BLDC motor to drive load, produce a sufficient torque, and maintain the speed. The rotor position of the rotor is sensed using Hall Effect position sensors and converts to back emf. According to BLDC Motor principle calculating back EMF in clockwise motion in Table 1, and electromagnetic forces of 6 gating signals shown in Table 2.

Table 1: Clockwise Rotation

Hall Sensor A	Hall Sensor B	Hall Sensor C	EMF A	EMF B	EMF C
0	0	0	0	0	0
0	0	1	0	-1	1
0	1	0	-1	1	0
0	1	1	-1	0	1
1	0	0	1	0	-1
1	0	1	1	-1	0
1	1	0	0	1	-1
1	1	1	0	0	0

Table 2: Gate Logic

EMF A	EMF B	EMF C	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	1	0	0	0	1	1	0
-1	1	0	0	1	1	0	0	0
-1	0	1	0	1	0	0	1	0
1	0	-1	1	0	0	0	0	1
1	-1	0	1	0	0	1	0	0
0	1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

CONTROLLING CIRCUIT

Design of Fuzzy PID Control

The PID is a Proportional- Integral- Derivative controller. In this controller the comparison between of actual speed and the reference will be done by error detection. In this block the error is detected and passing to VSI to vary the average voltage. According to PID controller fundamentals, the transfer function in equation 1 from the PID controller Figure 3.

$$K_P + \frac{K_I}{S} + K_D S = \frac{K_D S^2 + K_P S + K_I}{S} \tag{1}$$

Where K_P = Proportional gain, K_I = Integral gain and K_D= Derivative gain.

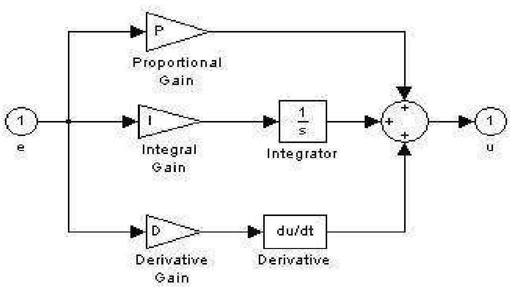


Figure 3: Simulation Model of PID Controller

Here in the PID controller an error the proportional gain (K_P) decreases the rise time, the Derivative Gain (K_d) reduces the overshoot and settling time, the Integral gain (K_i) eliminates the steady state error. The control variable u is shown in equation 2.

$$u = K_p\, e + K_i \geq e\, dt + K_d \frac{de}{dt} \tag{2}$$

From the design of PID controller most of industrial closed-loop processes and applications uses this controller. But the main disadvantage of this controller is it does not provide optimal performance.

Here in this proposed algorithm calculating the characteristics of the closed-loop control system mentioned below,

- **Rise Time:** The time taken for the output of a system to change from a specified small percentage of its steady-state increment to large percentage (usually 90 or 95).
- **Overshoot:** The maximum peak value of the response curve measured from the desired response of the system
- **Settling Time:** The time required for the response curve to reach and stay at maximum peak value.
- **Steady-State Error:** It differs to steady-state output value to the desired output value.

For obtaining efficient and stable system for PID controller we must be following the below steps.

- It is a advisable to obtain the open-loop response of the system first and to improve the system parameters.
- Both rise time and steady state error reduce using of proportional gain.
- Obtain the dynamic output response as well as decrease the overshoot adding of derivative gain.
- Removing the steady state error to adding of integral gain.

Here proportional gain (K_p), Integral gain (K_i), Derivative gain (K_d) values given Table 3.

Table 3: PID Values

Controller	K_P	K_I	K_D
PID	0.8	48	0.01

Design of Fuzzy PID Control

The speed controller circuit, the primary component of this control technique is a Fuzzy PID controller. Here the actual speed and reference speeds are compares then error rectifies given to the controller. The speed is controlled indirectly in VSI to varying the voltage. According this proposal the Fuzzy PID controller performs in inner loop controlling by the torque of the motor. Actual speed is controlled by the outer loop.

In this drive for achieving optimal tracking performance, the motor speed error ‘E’ and change in error ‘CE’ are used as input linguistic variables to the speed controller. The minimum number of rules are designed by mamdani type to obtain output of Fuzzy PID controller. Here 49 rules are designed. The fuzzy logic rule is designed by the form of

IF e=Ei and de=dEj THAN $U_{PD}=U_{PD}(i,j)$.

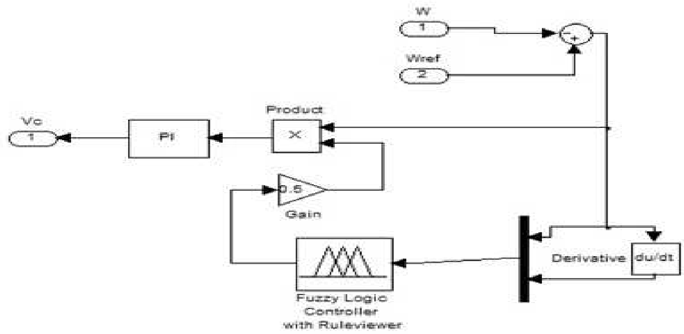


Figure 4: Simulation of Fuzzy PID Controller

In this Fuzzy Logic controller using multi input and single output system as two inputs and one output. Here error (e), change in error (de) are the inputs of the system. the outputs can be defined from linguistic rule as follows NL, NM, NS, Z, PS, PM, PL. these inputs and outputs are normalized the interval of [-10, 10] in Figure 5.

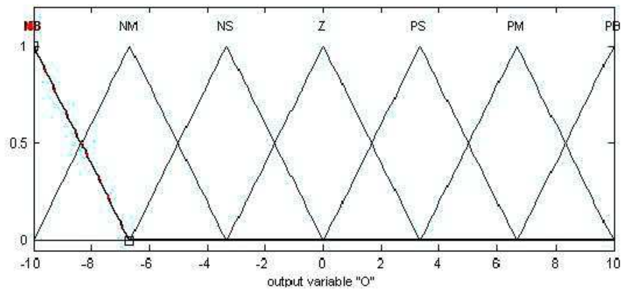


Figure 5: Membership Functions of Output

The two input fuzzy controller with coupled rules formed by combining both PI and PD actions.

The final fuzzy PID controller signal can be given as:

$$U_{PID}(t) = S_u \left\{ K_{PI} \sum_{i=0}^{t} U_{PD}(i) + K_{pI} U_{PD}(t) \right\} \tag{3}$$

From the fundamentals of linguistic manner by forming IF-THEN rules describes the Fuzzy sets, here ‘Negative Large’ (NL), ‘Negative Medium’ (NM), ‘Negative Small’ (NS), ‘Zero’ (Z), ;Positive Small’ (PS), ‘Positive Medium’ (PM), ‘Positive Large’ (PL). The arrangement of sets Table given below IV. In Fuzzy Logic algorithm design and implementation of minimum number of rules based on the knowledge of human here in this system consists of 49 fuzzy rules.

Table 4: Table of Fuzzy Rule

CE\ E	NL	NM	NS	Z	PS	PM	PB
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NL	NM	NS	Z	PS
NS	NL	NL	NM	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PM	PL	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

CALCULATION OF TOTAL HARMONIC DISTORTION (THD)

The total harmonic distortion, or THD, of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

$$THD = \frac{\sqrt{(V_2^2 + V_3^2 + \ldots\ldots + V_n^2)}}{V_1} \pm 100\%$$

Where V_1 is Fundamental Voltage Value and $V_{n\,(n=1,2,3,\ldots..n)}$ are Harmonic Voltage Values.

SIMULATIONS RESULTS AND DISCUSSIONS

To evaluate the performance of the system, a series of measurements has been accomplished. The performance comparison between PID controller and Fuzzy PID controller of three phase BLDC Motor is shown as follows.

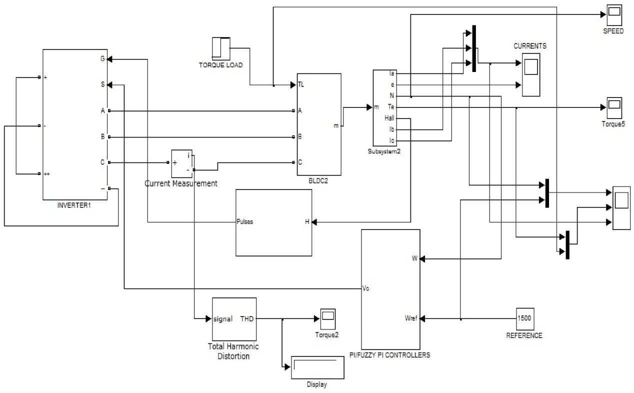


Figure 6: Simulation Model of PI and Fuzzy PI Controllers BLDC Motor

Figure 7 & 8 shown performances of the Fuzzy PID controller and PID Controller of BLDC Motor on Reference speed of 1500rpm with no load condition of Input Currents and Speed respectively. The results show that PID controller reach settling time is 0.25 sec, but in fuzzy PID controller reach the settling time of 0.10 sec.

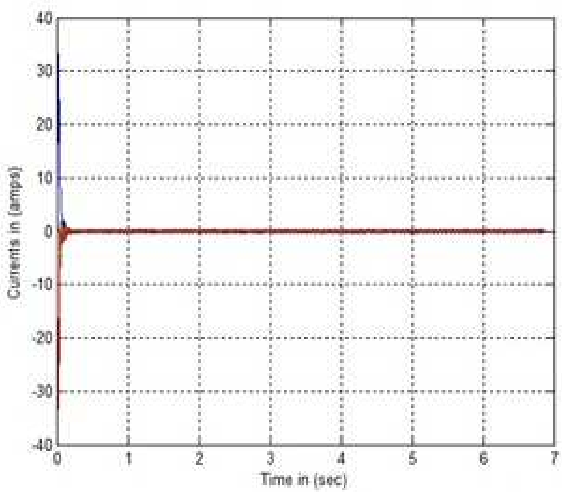


Figure 7: Input Currents at Reference Speed 1500 Rpm without Load

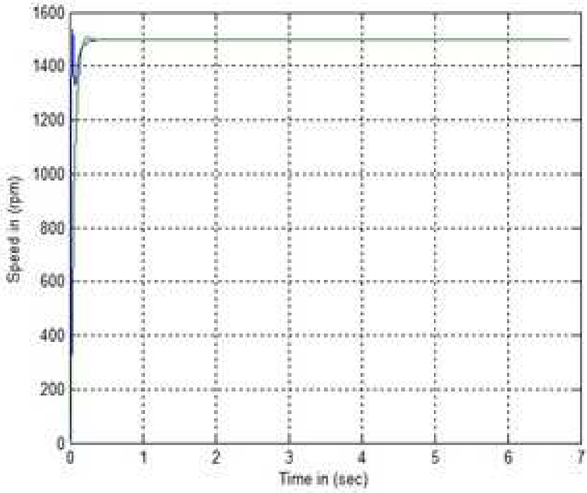


Figure 8: Speed at Reference Speed 1500 Rpm without Load

Figure 9 & 10 shows performance of the Fuzzy PID controller and PID Controller of BLDC Motor on Reference speed of 1500rpm with no load condition of Total Harmonic Distortion and Torque respectively. The results show that conventional PID controller reach settling time is 0.25 sec, but in fuzzy PID controller reach the settling time of 0.10 sec.

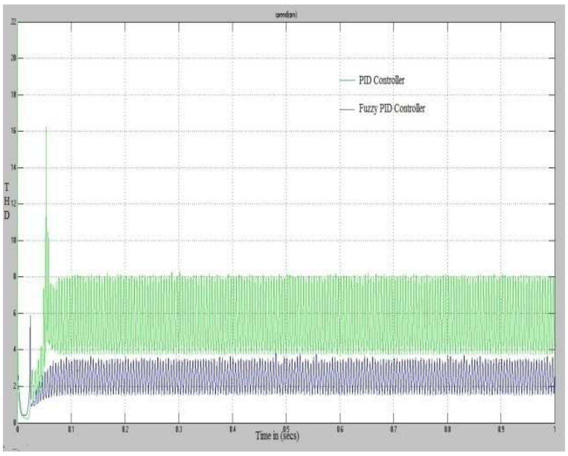


Figure 9: Total Harmonic Distortion (THD) at Reference Speed of 1500rpm without Load

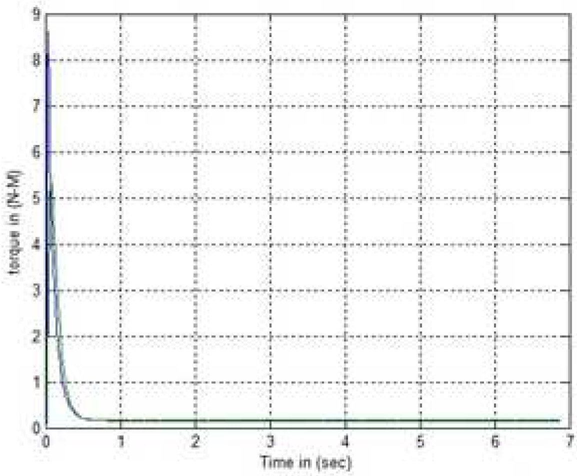


Figure 10: Torque at Reference Speed of 1500rpm without Load

At Reference speed at 1500rpm of BLDC motor Total Harmonic Distortion for Fuzzy PID controller is 2.47 and PID Controller is 3.25 at no Load.

Figure 11 & 12 shows performances of the Fuzzy PID controller and PID Controller of BLDC Motor on Reference speed of 1500rpm with load of 4 N-M condition of Input Currents and Speed respectively. The results show that PID controller reach settling time is 0.25 sec, but in fuzzy PID controller reach the settling time of 0.10 sec.

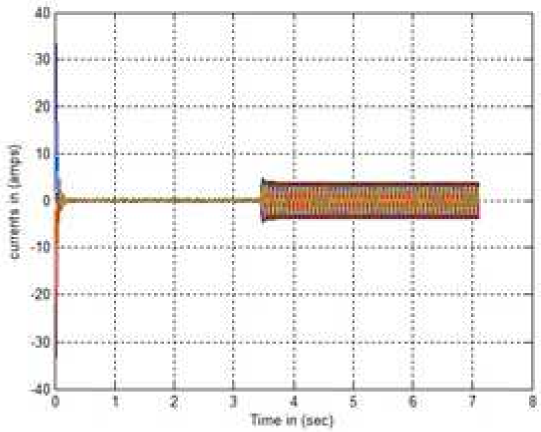


Figure 11: Input Currents at Reference Speed 1500 Rpm with Load

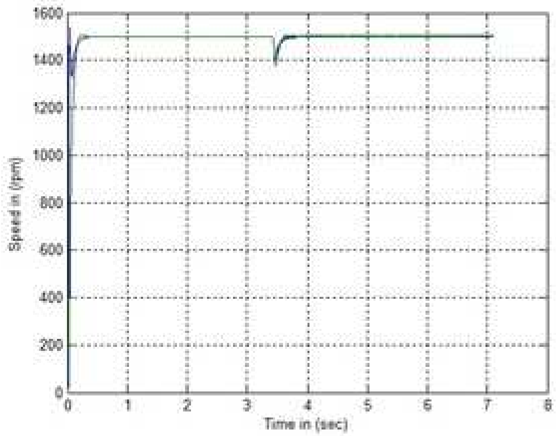


Figure 12: Speed at Reference Speed 1500 Rpm with Load

Figure 13 & 14 shows performance of the Fuzzy PID controller and PID Controller of BLDC Motor on Reference speed of 1500rpm with load of 4 N-M condition of Total Harmonic Distortion and Torque respectively. The results show that conventional PID controller reach settling time is 0.25 sec, but in fuzzy PID controller reach the settling time of 0.10 sec.

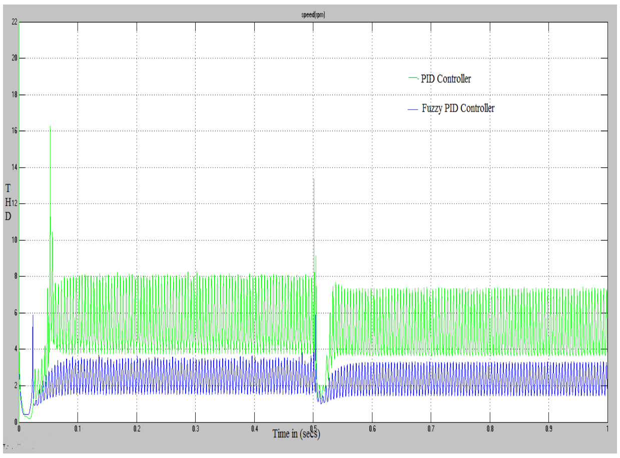


Figure 13: Total Harmonic Distortion (THD) at Reference Speed of 1500rpm with Load

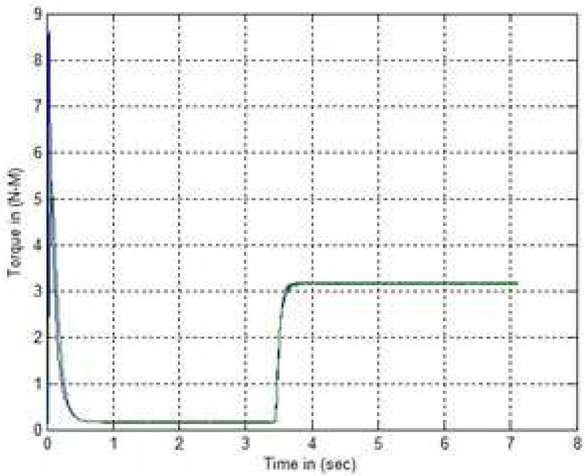


Figure 14: Torque at Reference Speed of 1500rpm with Load

At Reference speed at 1500rpm of BLDC motor Total Harmonic Distortion for Fuzzy PID controller is 3.1 and PID Controller is 4.143 with Load of 4 N-M at phase currents.

Figure 15 & 17 shows performance of the Fuzzy PID controller and PID Controller of BLDC Motor on at different speeds of without load condition of Speeds. The results show that PID controller reach settling time is 0.4sec, but in fuzzy PID controller reach the settling time of 0.2 sec.

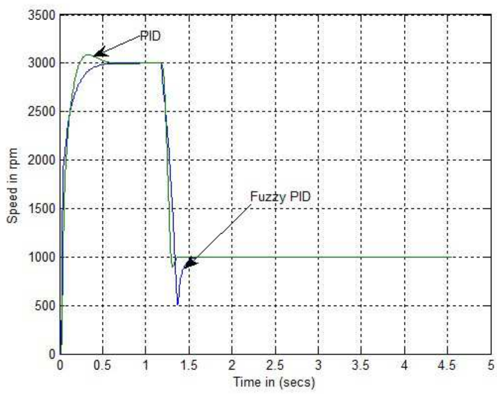


Figure 15: Motor Speed at Different Speed Levels without Load

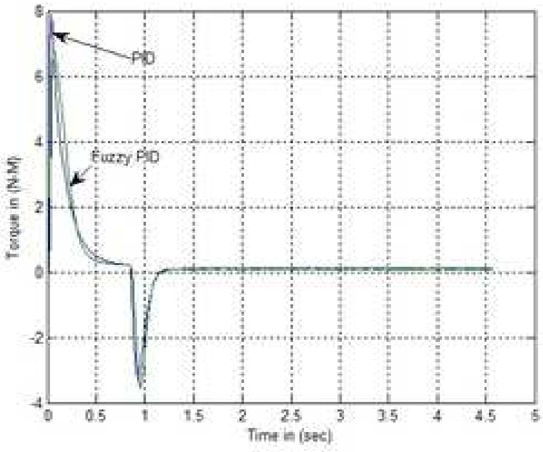


Figure 16: Motor Torque at Different Speed Levels with Load

Figure 16 & 18 shows performance of the Fuzzy PID controller and PID Controller of BLDC Motor on at different speeds with torque load of 3 N-M condition of torque. The results show that PID controller reach settling time is 0.4sec, but in fuzzy PID controller reach the settling time of 0.2 sec.

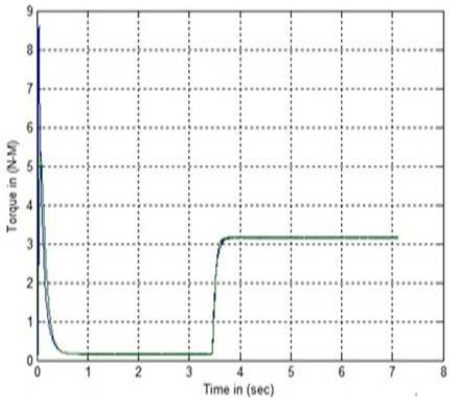


Figure 17: Motor Torque at Different Speed Levels without Load

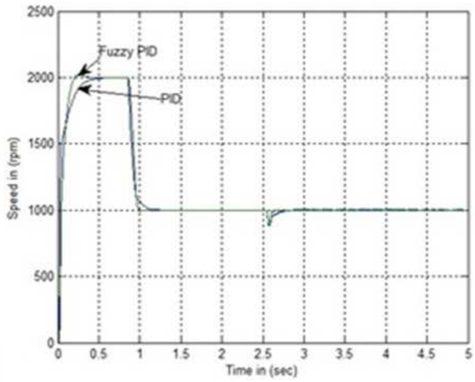


Figure 18: Motor Speed at Different Speed Levels with Load

CONCLUSIONS

In this thesis BLDC motor mathematical model is developed. Finally closed loop speed control BLDC is carried out and simulation results are presented. The performance evaluation results show that this modeling is very useful in studying the high performance drive before taking up the dedicated controller design concept for evaluation of dynamic performance of the motor.

It presents simulation results of conventional PID controller and Fuzzy PID controller of three phase BLDC Motor. With results obtained from simulation, it is clear that for the same operation condition the BLDC speed control using Fuzzy PID controller technique had better performance than the conventional PID controller, mainly when the motor was working at lower and higher speeds.

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